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Pakistan's overall energy potential assessment, comparison of LNG, TAPI and IPI gas projects

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ABSTRACT

Pakistan is facing severe energy crisis in spite of the fact that nature has blessed her with huge energy potential. Short fall of electricity supply in the country is increasing and has been recorded up to 4522 MW in 2010. This deficit reached to 7000 MW in May, 2011. A comprehensive review of Pakistan's energy sector is presented in this paper. Energy potential, major issues of energy sector and energy import options are discussed. Issues like poor management, combined cycle capacity, low hydro power share, circular debt and energy security have been covered. Energy potential assessment includes hydro solar, wind, coal, nuclear, hydrogen cells, geo-thermal, ocean resources and bio mass. Future prediction calculations are based upon country's current and world's average per capita energy consumption. Current oil and gas reserves of the country contribute to only 5 percent and 48.8 percent of the energy mix and at the current rate will be exhausted by 13 and 16 years respectively. The overwhelming dependence of the energy sector on imported fossil fuels may create a situation of energy security threat. However dependence upon the energy import options cannot be avoided in order to lessen the severity of energy crisis in near future. Some of the energy import options are: Turkmanistan, Afghanistan, Pakistan and India (TAPI); Iran, Pakistan and India (IPI) gas pipelines; Liquefied Natural Gas (LNG) from Qatar etc. On the other hand exploitation of vast renewable potential like hydro, solar and wind requires serious attention. Exploitation of indigenous coal resources would also be a key for solving energy crisis in the long run. In summary, this paper presents energy potential assessment in context of major issues, future predictions and impact of energy import options. This in turn provides a big, clear and brighter picture of the country's energy sector.

Contents

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1. Introduction

Energy is the soul of modern machine age. Human race has progressed to implausible heights during this period. Machines have automated human life but they require continuous and reliable energy supplies to maintain the progress of development. A short brownout shows the significance of reliable electricity supplies in each and every walk of life, especially in urban areas. Higher the energy consumption in a country, higher is the development and overall progress. That is why the per capita energy consumption of a country is taken as a measure of its socioeconomic development.

According to the International Energy Agency (IEA), the total primary energy supply of the world has increased to 12,717 Million Tons of Oil Equivalent (MTOE) in 2010 as compared to 6107 MTOE in 1973. The main contributors in this primary energy mix are: oil, 32.4%; coal/peat, 27.3%; bio fuels, 10%; hydro, 2.3%; nuclear, 5.7%; natural gas, 21.4% and other resources, 0.9% [1]. The worldwide fossil fuel resources are declining at an escalated pace and their prices are unpredictably volatile which have negative effects on the global economy. In addition, adverse effects of their abundant use include: increased pollution level, depletion of ozone layer, damage to the eco system and unprecedented change in the climate of the planet. The fossil fuels are irreplaceable at present and they will of course be of high value to the future generations as well. This scenario has stressed the world to search for new and efficient methods for harnessing the renewable energy resources in order to decrease the dependence on fossil fuels. Renewable energy resources are inexhaustible, indigenous, cleaner and ubiquitous in nature. The integration of these renewable resources to meet the 21st century energy requirements and the digitization of existing grid in order to enhance the reliability has enhanced the scope of smart grid. In olden days electricity was denoted as a sign of luxury, but now it is a basic necessity of everyday life. Limited electricity and gas supplies have administered devastating effects in every field of life in the country. Still around 40,000 villages are without electricity in Pakistan [2]. Long lines of vehicles in front of Compressed Natural Gas (CNG) stations are an indication of the severity of the on-going energy crisis. Violent protests are one of the serious consequences of this energy shortfall.

The paper is organized as follows: a review of similar research work is given in the next section. The prevailing situation of energy crisis in Pakistan has been presented in Section 3. Major issues of the energy sector are explained in Section 4. Regional energy security, TAPI, IPI and LNG import options are elaborated in Section 5. Future predictions and energy potential of the country are presented in Sections 6 and 7 respectively. Assessment of overall potential has been presented in Section 8 and conclusions are drawn in Section 9. Abbreviations used in the rest of the paper are summarized in Table 1.

2. Literature review

Shortage of conventional energy resources due to expanding population has been the main thrust behind many research papers. In [3], the energy supply situation in the rural sector of Pakistan has been discussed and energy shortage problem has been identified through a survey. It has been concluded that

Table 1
Abbreviations used.

AJK	Azad Jammu and Kashmir
CNG	Compressed natural gas
LNG	Liquefied natural gas
TAPI	Turkmanistan, Afghanistan, Pakistan and India
IPI	Iran, Pakistan and India
CSP	Concentrated solar power
GoP	Government of Pakistan
FATA	Federally administrated tribal area
GWEC	Global wind energy council
GWh	Giga watt hour
HDIP	Hydrocarbon development institute of Pakistan
IMF	International monetary fund
IPP	Independent power producer
KANUPP	Karachi nuclear power plant, Pakistan
KW	Kilo watt
KWh	Kilo watt hour
MWh	Mega watt hour
TWh	Tera watt hour
MAF	Million acre feet (a unit used for water storage capacity)
Mcft	Million cubic feet
MoU	Memorandum of understanding
MoWP	Ministry of water and power
MTOE	Million tons of oil
NTDC	National transmission and despatch company Pakistan
PAEC	Pakistan atomic energy commission
PEPCO	Pakistan electric power company
PKR	Pakistan rupee
PPIB	Private power infrastructure board, Pakistan
PV	Photovoltaic
REN21	Renewable energy policy network for 21st century
USD	US dollar
WAPDA	Water and power development authority, Pakistan
BCFD	Billion cubic feet per day
MMSCFD	Million standard cubic feet per day
TCF	Trillion cubic feet
AMI	Advanced metering infrastructure
HEMS	Home energy management system
MMBTU	Million British thermal unit

introduction of renewable energy resources can raise the standard of living in the rural sector. In [4], technology roadmaps used extensively in the renewable energy sector, have been analyzed. The authors argued that such roadmaps bring a consensus among various stakeholders and create a common vision as well as increase the contribution of renewable resources. It was concluded that regular review of these roadmaps is required to meet the changing needs and technologies. An overview of the available sustainable energy options has been presented in [5], however apart from rising fuel prices the grounds of the existing energy crisis have not been investigated. Authors in [6] suggested that a national policy should be formulated to increase the use of biogas in the energy mix of the country in order to reduce the import bill. It has been evaluated in [7] that wind energy being a mature form of renewable energy has an estimated payback period of five–eight years. The study concludes that wind power is competitive to conventional thermal power at most of the locations along the coastline of Pakistan. Sahir et al. [8], discussed that in future the disruption of supplies due to terrorism on the international trade routes is more likely to threaten the energy security which could result in an even worse energy crisis. It has been argued in [9] that a positive relationship exists between renewables and energy imports. This means that when an economy is in great demand of energy, it not only imports more conventional energy but also exploits more renewable energy. In [10], an analytic hierarchy process model has been used to prioritize four types of renewable energy technologies. Opinions of experts from universities and industry were obtained using a survey tool.

There is huge potential of solar generation in Pakistan but due to higher costs, the solar photovoltaic option is only suitable for areas far away from the grid. Current energy scenario and the issue of security in Pakistan have been presented in [11]. It has been found that solar energy, due to a fairly stable and consistent availability, is a much more economical choice for Pakistan as compared to wind energy. In [12], it has been concluded that the renewable resources may supplement the long-term energy needs of Pakistan but cannot serve as a substitute to conventional energy. Because harnessing of the energy cannot be perceived on the potential alone. In [13], the tremendous potential of biomass has been discussed. It has been concluded that necessary resource allocation coordination is required in order to fully utilize the biogas technologies. Alam Zaighum in [14] concluded that detailed feasibility studies are required in order to harness the geo-thermal potential. Analyzed geo-tectonic framework suggests that Pakistan does not lack in commercially exploitable sources of geothermal energy. Advantages and disadvantages of hydrogen energy have been discussed in [15]. The authors concluded that the hydrogen economy can help reducing dependence on oil imports, create sustainable environment and economic competitiveness in Pakistan. However, serious efforts are required to meet the challenges for realization of hydrogen ecomomy in the country. In [16], the main hurdles and challenges in the way to achieve future sustainable development have been discussed. In [17], it has been emphasized that the deployment of wind power system in Islamabad, capital of Pakistan, is not a feasible option. However, a wind power generation system installed on Margalla hills (having a height of 80 m) may show promising results. Current and future potential of renewable energy resources has been estimated in [18]. This estimate helps choosing the most promising renewable technologies. It has been concluded that the renewable energy has 8 times more potential than the total electricity demand in Pakistan.

Implementation of smart grid is an important aspect of energy savings and demand side management for future electricity requirements. Issues, challenges and advantages of smart meters and Advanced Metering Infrastructure (AMI) has been covered in [19]. It also includes various technologies and features that can be included in smart meters. The authors have also mentioned design, implementations and utilization challenges about AMI. Suitability of ZigBee for Power monitoring and control has been demonstrated in [20]. Different power controlling mechanism and network architectures give an insight to energy savings in future smart grid. Dynamic demand response management, which is a desirable feature of smart grid system, can be integrated with individual household profiles using Home Energy Management System (HEMS). A HEMS for smart grid designed with Zigbee sensors and a LABVIEW interface [21] has proved peak load reduction and cost effectiveness. Reviews of HEMS and optimization techniques proposed in context of smart grid for effective demand side management and energy efficiency have been carried out in [22,23].

Vital policy mistakes regarding sustainable development through renewable energy in Pakistan have been identified in [24]. It concludes that community participation for the promotion of sustainable development is indispensable. In [25] emphasis has been made on the installations and on-going activities of renewable energy projects in the country. Suggestions for effective planning and exploitation of renewable resources have been laid down. In order to enhance the contribution of renewable projects these suggestions are equally important for the third world countries besides Pakistan. In [26], it has been stated, in light of available renewable energy resource data, that the priority for exploitation should be made in the following order: (1) solar, (2) biogas, (3) micro-hydel, (4) wind and (5) geothermal energy. However, it does not show the existing situation of energy crisis in the country.

This paper provides a better picture of energy crisis in the context of major problems of the energy sector along with the future predictions and energy import options. Future prediction of energy demand on the basis of country's current and world's average per capita consumption has also been made in order to assess the severity of the energy crisis in future. In this research the existing renewable technologies around the world with their potential in Pakistan has been discussed. The optimized use of these technologies can help the country come out of the prevailing energy crisis.

3. Current energy scenario of Pakistan

Pakistan is a developing country of approximately 181.3 million people [27] and is facing acute energy shortage. In 2010, it had to import 21.64 MTOE of energy in order to fulfill its primary energy requirement of 63.09 MTOE [28]. Short fall of electricity supply in the country is increasing with demand and has been recorded up to 4522 MW in 2010 for many times of year. This deficit reached to 7000 MW in May, 2011 [29]. The Gross Domestic Product (GDP) growth has fallen sharply from 3.8% in 2010 to 2.4% in 2011 whereas the inflation rate in the country has risen from 10.1% to 13.7% during the same period [30]. Furthermore, limited natural gas supplies to domestic and industrial users, has intensified the severity of the energy crisis. In 2010, the indigenous oil and gas production was 64,948 Barrels/day and 4063 Mcft/day respectively. According to Hydro Carbon Development Institute of Pakistan (HDIP), the balance reserves of oil and gas by ending June 2010 were 41.13 MTOE and 498.70 MTOE respectively. If the demand and supply remains unchanged, it can be calculated that the known oil and gas reserves will exhaust in nearly 13 and 16 years respectively as follows:

$$\text{Oil production in 2010} = O = 3.180\ \text{MTOE} \tag{1}$$

$$\text{Gas production in 2010} = G = 30.812\ \text{MTOE} \tag{2}$$

$$\text{Balance Oil Reserves (30th June 2010)} = BO = 41.13\ \text{MTOE} \tag{3}$$

$$\text{Balance Gas Reserves (30th June 2010)} = BG = 498.7\ \text{MTOE} \tag{4}$$

$$\text{Years for exhaustion of existing oil reserves} = YO = BO/O = 13\ \text{years} \tag{5}$$

$$\text{Years for exhaustion of existing gas reserves} = YG = BG/G = 16\ \text{years} \tag{6}$$

this shows that under current demand and supply scenario the oil and gas reserves will exhaust by 2020 and 2026 respectively. This clearly indicates that Pakistan desperately requires the quest of other energy options for solution of its energy crisis on war-footing basis.

4. Major issues of the energy sector

In 2010, Pakistan's energy mix comprised of nearly 88.2% fossil fuels whereas hydro and nuclear constituted to 10.6% and 1.1% respectively. Similarly the electricity generation is primarily dependent on thermal power plants which contributed to nearly 67.3% of the electricity generated. Hydro and nuclear power constituted to 29.4% and 3.03% of the electricity generated while 0.26% was imported from neighboring countries. Contribution of hydro power in production of electricity reduces to only 11% in winter due to seasonal variations in flow of water, forced and maintenance outages, etc. [31]. The major issues being faced by the country's energy sector are shown in Fig. 1.

4.1. Decreased share of hydro power in the energy mix of the country

In 1960, hydro power contributed to 64.9% of the electricity generated in the country but by 2010 its share reduced to only 29.4%. The growth of nuclear generation has been more or less stagnant and only 787 MW could be installed up till now. The obvious option left to meet growing demand was through expensive thermal generation. This shift of the principal generation from hydro to thermal increased the cost of generation due to the hike in fossil fuel prices. It also worsened the reliability of the electrical grid due to availability problem of fossil fuels and initiated the issue of circular debt. This in turn created massive inflation and great unrest amongst the general public.

Pakistan has an agriculture based economy. Dams not only supply water for irrigation but also provide protection against floods. Norway, Brazil, Iceland, Canada and Austria produce 99%, 92%, 83%, 70% and 67% respectively of their electricity through hydro power [32]. China has some 22,000 dams with storage capacity of 2280 Million Acre Feet (MAF) approximately. USA has around 5500 dams while India has 650 undertaken dam projects with total of over 4000 dams [33,50]. In contrast, Pakistan's storage capacity is only 8% of its annual surface flow share of 142 MAF [34]. The last sizeable construction was the 1450 MW Ghazi Brotha run-of-the-river project. The construction of Kalabagh dam is unlikely to start due to severe controversy between political groups whereas the construction of the proposed 4500 MW Diamer Basha dam has been delayed for more than ten years. Hydro power is the most established form of renewable generation. Dams engage a huge capital but on the other hand they also generate the lowest per unit cost of electricity.

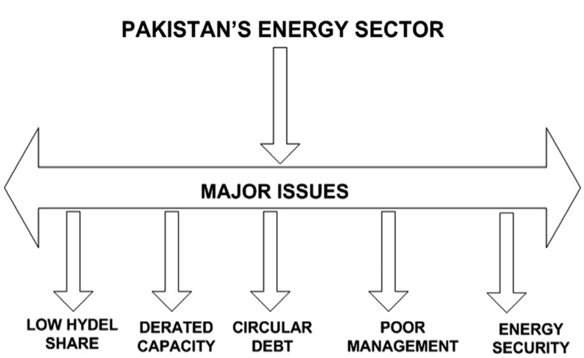

Fig. 1. Major issues of energy sector.

4.2. De-rated capacity

The total installed capacity up till June, 2011 was 24,173 MW but still extensive load shedding was experienced throughout the country [35]. Whereas the company wise share of electricity generation in the country was: Pakistan Electric Power Company (PEPCO), 50%; Independent Power Producers (IPPs), 38.6%; Karachi Electric Supply Company (KESC), 8.4% and Pakistan Atomic Energy Commission (PAEC), 3% [36]. Up till June 2011, the installed capacity of the largest company in Pakistan i.e. WAPDA/PEPCO was 20,986 MW whereas the dependable capacity had de-rated to 18,734 MW. But maximum system capability averaged from the past four years is 15,190 in summer and 13,815 MW in winters [37]. This is due to various reasons like the problem of silt, decreased efficiencies of thermal plants, periodic lows in the flow of water, problem of circular debt, fuel availability, forced and maintenance outages, auxiliary consumption and transmission limitations etc. Electricity generation starts to de-rate immediately after installation and requires scheduled maintenance. Thermal generation in the public sector was not allocated suitable funds; it caused rapid decrease in generation capability.

4.3. Circular debt

Failure of PEPCO, central power purchasing company, in maintaining cash flows to its suppliers is termed as 'circular debt' of energy sector. Circular debt has decreased reliability of national grid and is one of the major causes of load-shedding. Current circular debt of power sector has reached 313 billion rupees [38]. Issue of circular debt arose due to imbalance in generation cost and revenue collected by PEPCO.

The reason for poor revenue collection and the pile up of circular debt are shown in Fig. 2 and detailed below

First reason is promotion of thermal production in the energy mix. Bulk share of thermal power projects in the energy mix is

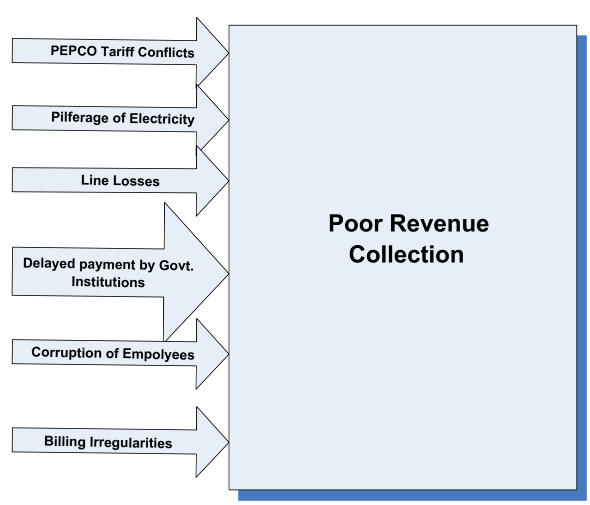

Fig. 2. Reasons of poor revenue collections.

responsible for high cost of electricity. In 1960s, contribution of the hydro power was almost two third of the total supplies. But the role of international and national lobbies to guard their vested interests in the promotion of thermal has contributed to the current high electricity prices, inflation and decreased reliability of national grid. IPPs contribute 38.6% of the generation and require timely payments every month to meet their expenses, but the escalation in fuel prices and delay in payments by huge Government institutions resulted in the situation of circular debt.

Second reason behind circular debt is poor revenue collection. Insufficient tariff, pilferage of electricity, corruption, losses, dispute on tariff with FATA, AJK and KESC all contributed to the cause. Delay in payments by federal and provincial institutions further elevated the situation.

Third reason is withdrawal of subsidies by Government of Pakistan under the pressure of IMF. This resulted in increased tariff as PEPCO was already unable to meet its expenses due to losses incurred. Per capita income of the country is USD 1258 only [39]. Cost of electricity was already high due to increased share of thermal generation; this in turn promoted the illegal use of electricity resulting in further decrease in revenue. PEPCO contributes to almost 50% of the power generation in the country, but is itself dependent on the basic energy suppliers for its operation. Basic energy suppliers include oil marketing companies and gas suppliers. In June, 2006 PEPCO availed bank loans against government guarantees to overcome the effect of withdrawal of subsidies. The situation was further exaggerated by the huge line losses and poor revenue collection from Government offices and as a result PEPCO started delaying payments to the basic energy suppliers and the IPPs in August, 2006 [38]. In this way the monetary problem of PEPCO cascaded down to the basic energy suppliers and they were stressed to engage banking sector to balance their cash inflows. The mechanism of the circular debt is shown in Fig. 3.

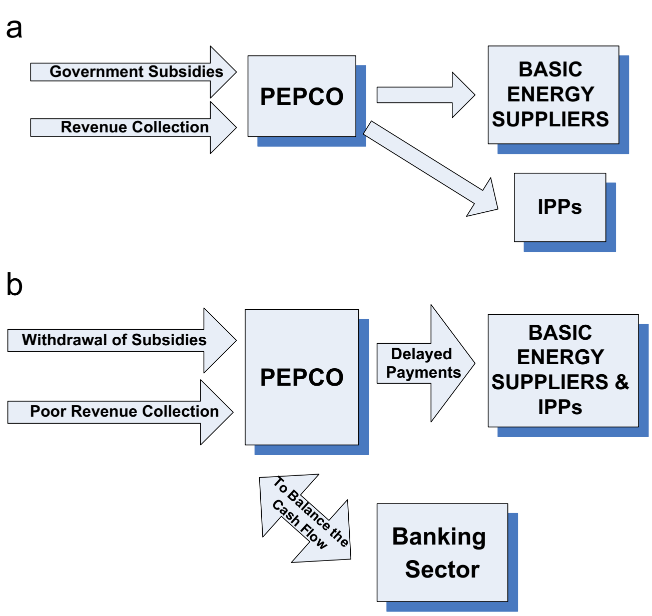

Fig. 3. Mechanism of circular debt.

4.4. Management issues

The policy frame work and its management are under strong political influence. Circular debt is one of the many issues generated from poor management. Introduction of rental power plants portrays the political influence on policy frame work of power sector. Ignoring merit, appointments of non-eligible employees on political basis etc. are some examples of management concern. Non technical losses or electricity theft is another aspect of poor management. A detailed review of electricity theft identification and control has been presented in [40]. In 2011, the technical losses of PEPCO were 20.85% with 90,575 GWH generated and 18,877 GWH lost at an average unit sale price of Pakistani Rs. 6.25 [35]. Since we know that percentage losses (PL) can be calculated by

$$PL = \text{Energy Lost}/\text{Energy Generated} \times 100 \tag{7}$$

a reduction of 1% of this loss would result in savings (SV) of approximately US dollar 62.9 million and can be calculated as follows:

$$SV = 1\% \times \text{Energy Generated} \times \text{Rate (PKR)} \tag{8}$$

$$SV = 1\% \times 90575 \times 6.25 = \text{PKR } 6.038 \text{ billion} \tag{9}$$

$$SV = \text{USD } 62.9 \text{ million}, \ (1\text{USD} \sim \text{PKR } 96) \tag{10}$$

4.5. Energy security and regional situation

The dependence of Pakistan's energy sector on imported oil has created serious doubts on the energy security of the country because international routes for shipment of the oil for Pakistan may be battlefield of some international conflicts. Furthermore, in case of war the blockage of the sea ports may halt the entire thermal electricity generation. The indigenous oil and gas reserves will be depleted in 13and 16 years respectively. In future, the wealthy nations will outbid other countries in the run for energy import. Pakistan is in negotiation with its neighboring countries to solve its energy crisis. The project of Iran gas pipeline, import of 10,000 MW electricity from Iran and import of LNG and LPG from Qatar is underway. Similarly, import of 10,000 MW electricity from Kirghizstan and Tajikistan (CASA-1000), 1000 MW from Uzbekistan is in the feasibility phase. India has also offered 10,000 MW of electricity export to which Pakistan is seriously considering. But the political instability in Afghanistan and prevailing gruesome

Table 2
Comparison of TAPI and IPI gas projects.

Detail	IPI	TAPI
Route	Iran–Pakistan–India	Turkmenistan–Afghanistan–Pakistan–India
Power generation	4000 MW power generation in Pakistan	2500 MW
Gas (mmcfd)	60 to Pakistan and 90 to India	38 to Pakistan and India each, 14 mmcfd to Afghanistan
Transporting cost	Low processing and transportation cost to Pakistan	New silk route between Central and South Asia
Transit fee	200 million USD to Pakistan	217 million USD to Pakistan
Economic effect	Economic boost in pipe line route	Economic boost in pipe line route
Length	2775 km	1680 km
Route	South Paras Field Iran–Baluchistan –Multan (Pakistan)–India	Tolon field Turkmenistan–Afghanistan–Pakistan–India
Total cost	US dollars 7.5 billion	US dollars 6–7 billion
International support	Reservations of USA and EU due to involvement of Iran	Supported by IMF, World Bank and USA

situation of security in Sindh and Baluchistan has rendered the planned routes vulnerable. The regional and international strategic political concerns have made the success of these projects suspicious. The LNG import option from Qatar and comparison of TAPI and IPI gas import projects are discussed in the following section.

5. IPI, TAPI and LNG import options

Pakistan is generating 32% of its electricity from natural gas and has 27.5 trillion cubic feet balance of recoverable gas reserves. As discussed in Section 3, the current gas production is around 4 Billion Cubic Feet per Day (BCFD) whereas the demand is approximately 6 BCFD. The gas production is expected to fall to less than 01 BCFD by 2025 due to depletion of gas reserves and demand will increase to 8 BCFD. Almost one third of the indigenous natural gas is used for electricity generation (32%) which causes a severe domestic and industrial gas load shedding [41]. This has significantly damaged country's export earnings and increased the import bill. In view of the prevailing energy crises and exponentially decreasing gas reserves, importing gas from neighboring gas rich countries has become the need of the hour.

The current prevailing geo-political scenario in the region has put a question mark on the launch and completion of IPI gas pipeline proposed since 1993. As an alternate to IPI, TAPI gas pipeline project is required to be materialized at a rapid pace in order to meet the energy requirements of Pakistan in particular and the region in general. It is worth mentioning here that India has already withdrawn from the IPI project while Bangladesh has shown its interest in the TAPI project. Salient features of IPI and TAPI are summarized in Table 2.

The proposed IPI project would provide only 01 BCFD of gas at a cost of USD 1.25 billion. The proposed TAPI project would provide 3.2 BCFD to 3 countries at a cost of USD 7.6 billion. If both IPI and TAPI projects are completed, Pakistan will have secured around 3 BCFD as compared to a demand of 8 BCFD by 2025. Even then the demand supply gap will be around 5 BCFD because the existing indigenous gas reserves of the country shall have exhausted by 2026 as estimated in Section 3. In the light of above facts: it will not be possible to feed gas based power plants in future, contribute 32% of the power generation, if depended only on the above mentioned gas pipe lines [39]. Both IPI and TAPI gas pipe line projects require security guarantees as well as peace in the region.

While transportation of gas using long pipelines proves to be highly challenging and time consuming projects, LNG can prove to be an alternative means of long-distance transportation. LNG is stored and transported in liquid form in tanker ships. After delivery to the market, it is re-gasified and distributed via pipelines. In view of prevailing geopolitical and logistically challenging circumstances in the region burdened with tensions, construction of risky and time consuming pipeline projects would be less feasible. Taking the complicated political dynamics of the region into account, expanding the LNG trade and port capacity is preferable to developing potentially volatile pipelines. Prospects of bringing in LNG from Qatar, having the third largest gas reservoirs and being the largest LNG exporter, are needed to be thoroughly analyzed. Similarly agreements can be made to utilize the expertise from Australia, a major player in LNG market. It is pertinent to declare here that our neighboring country is getting considerable energy benefits from Qatar and Australia. For development of LNG resources, Indian skills and expertise may also be taken into account. LNG Plants are modular, compact and efficient. In addition to Qatar, India has also offered to export 200 Btu of LNG to Pakistan. The price proposed by India is USD 21 MMBTU including all the charges. This price is higher than the USD 18 quoted by Qatar and much higher than the USD 11 proposed by Dutch firm 4Gas Mashal LNG.

The IPI and TAPI Gas pipe line projects are highly dependent on the position of security and peace within Afghanistan. Although Afghanistan has demanded only the transit fee from Pakistan and India and has left her gas share from TAPI gas pipe line project but in future her requirements may need the establishment of gas infrastructures. It can be easily concluded that the LNG import options must be prioritized to the gas pipeline projects in order to ensure the availability of energy.

6. Future predictions

Pakistan's per capita electricity consumption is 457 KWh which is around one sixth of world's average of 2892 KWh. The comparison of per capita electricity consumption with some other countries is presented in Table 3.

The population and therefore demand for energy is increasing continuously. Current shortfall of electricity fluctuates between 4 and 7 GW and is expected to widen up to 14 GW by 2020 [41]. The current population of Pakistan is 181.3 million and is growing at a rate of 2.69% per annum. At this rate the population and electricity requirements by 2025 and 2050 can be estimated.

Pakistan's projected population in year 2025 (PP25) can be estimated as follows:

$$PP25 = 181.3\ (1+0.0269)^{x} \tag{11}$$

$$PP25 = 256 \text{ million}, \quad (x = 2025-2012) \tag{12}$$

similarly, the projected population in 2050 (PP50) can be estimated as follows:

$$PP50 = 181.3\ (1+0.0269)^{y} \tag{13}$$

$$PP50 = 497.1 \text{ million}, \quad (y = 2050-2012) \tag{14}$$

the per capita requirement is not same as per capita consumption due to a short fall of 4522 MW as recorded in 2010. The electricity requirement after including the load shedding factor has been computed as 78.8 TWh approximately (consumption side). The per capita electricity requirement has been computed as 640 kWh by NTDC. The per capita requirement is bound to increase owing to improvement in lifestyle and infusion of electronic/digital devices in every household. But even if the per capita requirement remains stagnant; the minimum electricity requirement of the population in 2025 and 2050 can be estimated.

Pakistan's electricity requirements in 2025 (PER25) can be calculated as follows:

$$PER25 = \text{Percapita} \times \text{Population (2025)} \tag{15}$$

Table 3
Comparison of per capita electricity consumption of some countries.

Country	Per capita elect. consumption in kWH
USA	13,361
Australia	10,063
France	7756
Germany	7217
Saudi Arabia	7967
UK	5741
China	2942
Turkey	2474
India	644
Pakistan	457
Highest per capita: Iceland	51,447
World average	2892

$$PER25 = 640 \times 256 = 163.8\ \text{TWh} \quad (16)$$

similarly Pakistan's electricity requirements in 2050 (PER50) can be calculated as follows:

$$PER50 = \text{Percapita} \times \text{Population (2050)} \quad (17)$$

$$PER50 = 640 \times 497.1 = 318.1\ \text{TWh} \quad (18)$$

these projected population and electricity requirements have been simulated in MATLAB to get a clear picture and are shown in Fig. 4. The results clearly show that the country's electricity requirements are predicted to be more than twice current demand by 2025 and four times current demand by 2050. But the progress in development of energy resources in the past does not show a promising picture for future needs. Only 787 MW of nuclear capacity could be installed between 1980 and 2011. The addition of only 7 GW of hydel capacity in the last 55 years has raised serious doubts on the achievement of future targets [41].

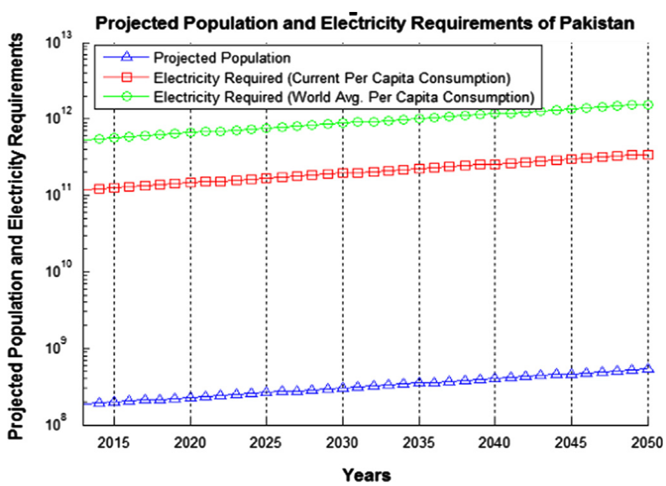

Fig. 4. Projected population and electricity requirements.

7. Energy potential

Pakistan has a huge potential of a variety of energy resources. The identification and quantification of this potential is necessary to make the country self-dependent. The detailed study to examine these resources is presented in following sub sections.

7.1. Hydro power potential

Hydra or water is one of the most significant components for human life. Per capita water availability is a measure of relationship between water and human life. More than 1700 m^3 availability shows that country has no water scarcity while below it shows stressed or seasonal scarcity prevailing in any country. Lower than 1000 m^3 means severe shortage of water in a nation; Pakistan is at the threshold of 1038 m^3. This is the result of delaying the development of water reservoirs.

Dams are probably world's largest man-made structures and require huge capital and an extended time period for completion. They not only help in generation of electricity by providing head but also provide water for irrigation and protection against floods. Storage capacity of dams reduce with time as they are filled with silt; but even when full of sedimentation, they can be operated as run-of-the-river plants. Hydro power is the most established of all renewable technologies and has a share of nearly 15.3% in the global energy mix with total installed capacity up to 970 GW at the end of 2011 [42]. At present, the country's storage capacity is only 8% of its annual surface flow share of 145 MAF. Terbela is the largest storage reservoir in the country with storage capacity of 9.69 MAF which is now reduced to 70% because of silt accumulation. Mangla has 5.05 MAF of storage capacity after upraising. Government has withdrawn from the controversial Kalabagh Dam project and the completion of 4500 MW Diamer Basha Dam is expected till 2022. The identified potential of large hydro power plants is 59 GW whereas the potential of small hydro projects in Gilgit is

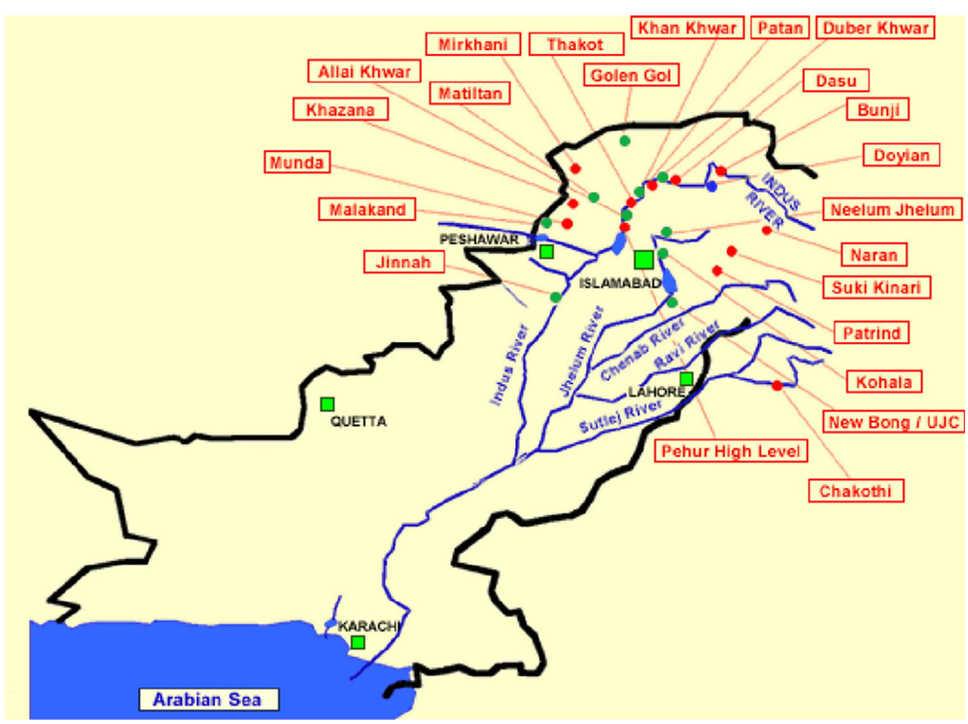

Fig. 5. Proposed sites for hydro power generation.

Table 4
Large individual power plants operating on solar technologies.

Name	Location	Capacity	Technology type
Aqua caliente solar project	Arizona,USA	247 MWp	Photovoltaic (PV)
Solar energy generating systems	Mojave desert, California, USA	354 MW	Parabolic trough
Martin next generation solar energy center	Indiana Town, Florida, USA	75 MW	Steam input into a combined cycle
Puerto errado	Murica, Spain	31.4 MW	Fresnel reflector
Maricopa solar	Peoria, Arizona, USA	1.5 MW	Dish stirling
PS20 solar power tower	Seville, Spain	20 MW	Solar power tower

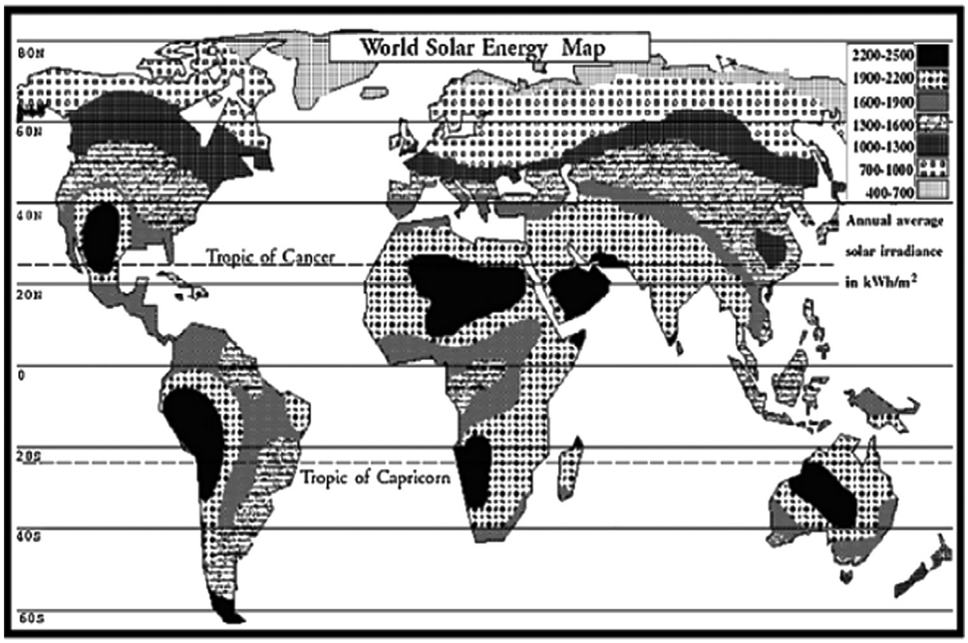

Fig. 6. World solar insolation map.

Table 5
List of countries with top ten wind power capacities.

Country	Installed capacities MW
China	62,634
USA	46,919
Germany	29,060
Spain	21,674
India	16,084
France	6800
Italy	6737
UK	6540
Canada	5265
Portugal	4083
World Total	237.7 GW

around 2000 MW [43]. The proposed sites for new hydro power plants are shown in the Fig. 5 [44].

7.2. Solar energy

Solar PV and solar thermal technologies are now established technologies and huge projects of bulk generation are underway in numerous countries. Solar generation is the most rapidly growing of all the renewable resources. In 2011, the global solar PV cumulative capacity increased by 74% to almost 70 GW. The size of global solar PV industry is now over USD 100 Billion/year. More than 450 MW projects were added to increase the global concentrated solar thermal power capacity by 35% and enhance the total to 1760 MW (mainly parabolic trough). Similarly, solar thermal heating and cooling increased by 27% to augment the global total consumption to 232 GW. The solar thermal technology is more efficient and has the benefit of comparatively easy storage and hybridization with other energy sources over solar PV. Stand alone power plants of large capacities operating in the world based on solar technologies are detailed in Table 4.

According to world solar map [45], shown in Fig. 6, prepared by NASA, Pakistan lies in the region where the insolation is around 1900–2200 KWh per square meter, which is the second highest region in the world [43]. The estimated potential of solar energy in the country is approximately 2900 GWH. The 178 MW solar PV plants at Pakistan Engineering Council and Planning Commission are the only on-grid solar pilot plants in the country. Lack of infrastructure and non-existence of photovoltaic industry in the country are barriers to solar energy development. The high per unit cost of solar energy is also a restriction to adopt solar energy at lower level.

7.3. Wind energy

According to the GWEC (Global Wind Energy Council) wind energy is now generated in over 75 countries with 21 countries having installed capacity above 1000 MW. In 2011, over 40 GW of capacity was installed increasing the world total to 238 GW approximately. A list of countries with top ten installed wind power capacities is presented in Table 5 for comparison [46].

Pakistan has a coastal line of around 1000 km. Speed of wind reaches up to the 7–8 m/s in this region. Wind map of Pakistan is shown in Fig. 7 [47]. This speed is one of the most suitable and exploitable wind speeds. Identified potential of Gharo, a coastal region, is approximately 55 MW. Government has issued licenses to some companies. A 50 MW project in Sindh has been instigated by a Turkish company. Government has also signed MoUs with China for production of 2000 MW electricity generation. Government has a target to install 30 GW wind power by 2030 in the country.

7.4. Biomass

Bio mass provides almost 10% of the global primary energy supplies and is the 4th largest source of energy. It can be in solid, liquid or gaseous form. It consists of the residues of different crops, wood, animal waste, municipal solid waste, processed industrial waste, biofuels and land fill gases etc. In 2011, electricity generation from biomass increased by 9% and the total installed global capacity is 72 GW. Pakistan has an agrarian economy and biomass has around 36% share in the basic energy mix of the country. Unluckily a huge amount of crops residue is being burned aimlessly instead of generating energy. However, recently sugar mills announced to produce 3000 MW from bagasse. Pakistan has a potential of 400,000 t of bio diesel which is environmental friendly and can be produced from non-edible oils. Castor bean is one of the heavily oil enriched seed which is self growing and found in arid areas of Pakistan. Castor oil; extracted from castor bean; is used in many medicines and is an important export for Pakistan. Its fascinating use is as a bio fuel. Processing of castor oil to convert into bio diesel is very easy compared to other methods of producing bio diesel. Dissolving castor oil into alcohol will convert it into bio diesel. Exploitation of biomass can help to reduce the energy crisis in a great deal.

7.5. Nuclear energy

Nuclear is one of the most significant and controversial industries in the world. It plays its role from the treatment of cancer, agriculture, strategic asset and concludes at provision of cheap nuclear power. France is generating 77% of its electricity from nuclear power plants whereas Pakistan is generating only 7.6% of its electricity from nuclear power. A list of some countries producing nuclear power is presented in Table 6 for comparison purposes.

Table 6
Comparison of nuclear power generation for some countries.

Country	Percentage of electricity generation
France	77
Slovakia	54
Belgium	54
Ukraine	47.2
Hungary	43.2
Slovenia	41.7
Switzerland	40.8
Sweden	39.6
South Korea	34.6
Armenia	33.2
Pakistan	7.6

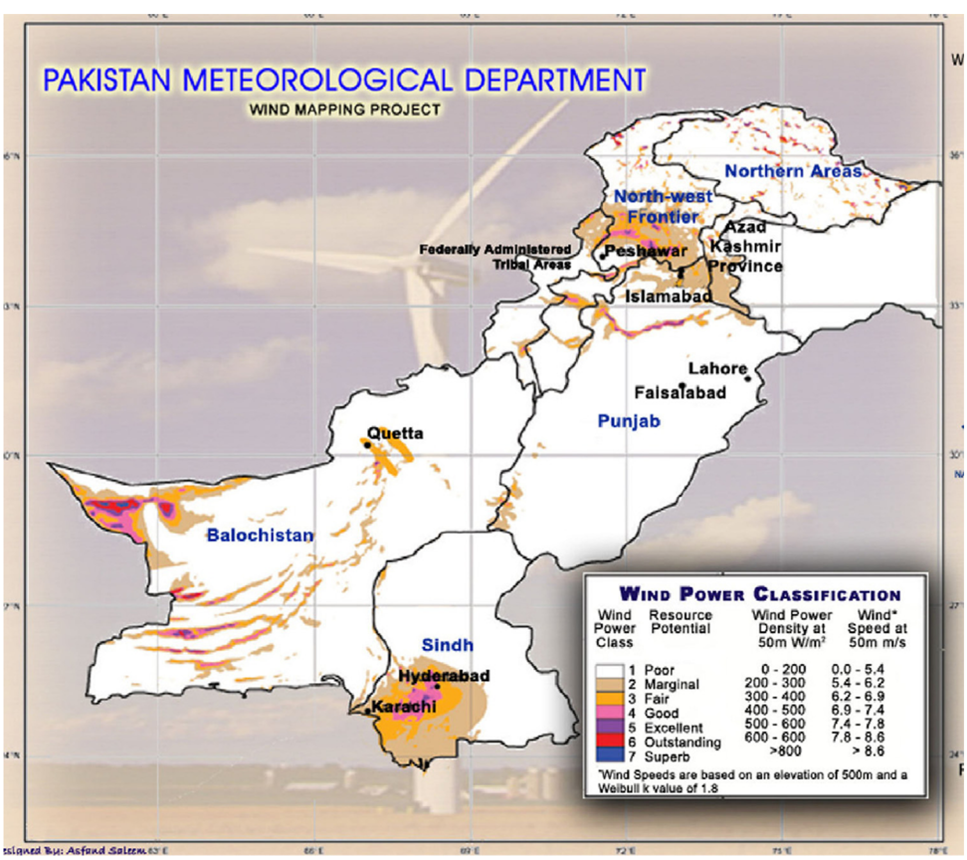

Fig. 7. Wind map of Pakistan.

Pakistan was the first in South Asia in 1970 s to enter in the era of nuclear power by launching the Karachi Nuclear Power Plant. The 137 MW was nearly 20% of the requirement of Karachi at that time. KANUPP is producing 80 MW now a day due to aging effects. KANUPP is based on the natural uranium and heavy water technology known as the CANDU (Canada Uranium Deuterium).

Advancement in the nuclear power program is made on the basis of Pressurized Water Reactors (PWRs). These reactors are based on natural water and enriched uranium. Two reactors C-1 and C-2, each of 350 MW, are operational at Chashma while two reactors (C-3 and C-4) of the same rating are under construction. Pakistan Atomic Energy Commission is trying to get 1000 MW nuclear power plants to install at Karachi in order to meet its target of generating 8800 MW by 2030.

7.6. Geo-thermal energy

According to some estimates, heat energy present in upper 10 km of the earth crust is 50,000 times the total oil and gas reserves of world [48]. It varies in ascending order from north to south. There are two types of the systems used for the geo thermal energy.

- Hydro-geothermal system.
- Enhanced geothermal system.

Hydro-geothermal energy systems deal with energy within 6 km of the earth crust. Underground water is converted into steam and then trapped in the earth rocks. Natural hot springs and geysers are renowned hydro geothermal systems. Enhanced geothermal energy deals with earth crust up to depth of 10 km. Geo-thermal energy can be used directly in the form of heat or converted to electricity. Around 78 countries utilize direct geo-thermal heat energy systems using ground source heat pumps which can provide heating and cooling. Geo-thermal heating provides an estimated 58 GW and Geo-thermal power adds an estimated 11.2 GW to meet global energy demand.

Geo-thermal is not explored in Pakistan though it has promising potential. Oil and gas companies have the records of their digging works which may prove helpful in assessing the feasibility of geothermal energy systems.

7.7. Hydrogen based energy resources

World is moving towards hydrogen economy i.e., the conversion of internal combustion engines to hydrogen fueled engines and development of the fuel cells. A fuel cell converts hydrogen and oxygen from air to electricity, water and heat. Fuel cells are categorized by the electrolyte used and can be classified, on the basis of their operating temperatures, into two main categories as follows:

1. Low temperature fuel cells (60–250 °C).
2. High temperature fuel cells (600–1000 °C).

Low temperature fuel cells have been largely deployed in transport applications owing to their quick start times, compact volume and lower weight compared to high temperature fuel cells. General types of low temperature fuel cells are proton exchange membrane fuel cells, phosphoric acid fuel cells, alkaline fuel cells, unitized regenerative fuel cells, direct methanol fuel cells etc. High temperature fuel cells are more efficient in generating electricity than low temperature fuel cells. In addition, they provide high temperature waste heat, which is a problem for transportation applications, but is a benefit in stationary generation applications.

Table 7
Potential of different resources in Pakistan.

Sr. no.	Source of energy	Potential
1	Oil reserves	498 MTOE approx
2	Gas reserves	41.13 MTOE approx
3	Hydro power	59 GW estimated
4	Solar energy	2900 GW estimated
5	Wind energy	55 GW estimated
7	Thar coal	2700 Million Tons (measured)
8	Small hydro	2 GW estimated
6	Nuclear power	Planned 8.8 GW up to 2030
9	Hydrogen based cells	Still needed to be quantified
10	Geo-thermal potential	-do-
11	Ocean related sources	-do-
12	Bio mass	-do-

General types of high temperature fuel cells are molten carbonate fuel cells and solid oxide electrolyte fuel cells.

In Pakistan there is a need to realize this shift towards the hydrogen economy. In first stage, hydrogen can be mixed along with natural gas to fuel the internal combustion engines. Development of the hydrogen storage and distribution networks may be taken in the midterm planning. It is expected that the world will shift to hydrogen economy up to the half of this century.

7.8. Thar coal and coal gasification

Coal provides almost 27.3% of the global primary energy supplies and is the 2nd largest source of energy. Burning of coal to convert it into coal gas under the earth in an environmental friendly manner is a well proven technology. There are following four techniques of coal gasification.

- Sasol–Lurgi dry ash.
- GE (originally developed by Texaco).
- Shell.
- Conoco Phillips E-gas (originally developed by Dow).

In Pakistan the contribution of coal is 6% in the energy mix and only 0.1% in electricity generation. Only coal power plant in Pakistan is at Lakhra with operating capacity of 30 MW. According to HDIP, the country had to import around 3.064 MTOE of coal amounting to Rs. 34,937 million in 2010. Thar coal reserves are the 5th largest coal field in the world, with an estimated 176 billion tons of coal, and are considered sufficient for the generation of 20,000 MW of electricity for the next 40 years [49]. The exploitation of the coal reserves has not been possible due to lack of mining and gasification technology.

Survey of Pakistan has determined the quality of coal using 2000 samples and showed that the coal is in range of Lignite B to Sub-bituminous A with relatively low in sulfur and ash contents. Low quality coal is suitably converted to coal gas which is mixture of carbon mono oxide, carbon dioxide ash and water vapors through Sasol Lugri technique [49].

7.9. Ocean energy

Energy can be captured from ocean waves, tides, salinity gradients and difference in ocean temperatures. There is a lot of potential with respect to ocean related technologies such as tidal waves, osmotic power and trapped methane sources under the surface of the ocean etc. The worldwide installed capacity of ocean power is 527 MW, mostly in the form of pilot projects. The tidal waves energy transformation technology is more mature than the osmotic and trapped methane conversion technology. Pakistan has

Table 8
Proposed enhancement of capacity using combined cycle technique.

Name of power station	Installed capacity (MW)	Additional proposed combinedcycle capacity (MW)
Jamshoro (GENCO-I)	3×200	3×100
Guddu (GENCO-II)	$2 \times 110 \cdot 2 \times 210$	$1 \times 100 \cdot 2 \times 100$
Muzaffargarh (GENCO-III)	$3 \times 210 \cdot 2 \times 200 \cdot 1 \times 320$	$3 \times 100 \cdot 2 \times 100 \cdot 1 \times 100$
TOTAL additional CCC proposed		1200

1000 km long coastal line. A lot of research scope exists to quantify and assess the feasibility of this potential.

8. Analysis of potential

At present there are two ministries and more than a dozen organizations under them that are responsible for the development of energy resources in Pakistan. It is proposed that an independent energy authority is required to study and formulate plans to meet the demand in the future. Pakistan has a huge potential of different energy forms as shown in Table 7. However, proper planning is required to harness these resources. These energy resources may be categorized on the basis of their total potential, technological maturity, economic feasibility, seasonal reliability etc. and strategies for short, medium and long term can be devised in order to meet the future energy requirements of the country in the most feasible manner.

8.1. Short term plan

Primary indigenous resources like small hydro, gas fired thermal plants and coal fired plants on the basis of coal gasification should be given top priority to address the immediate energy needs. These areas are technologically established, require relatively less capital investment and are sufficient for the country's energy requirements. Also Government is required to address the issue of circular debt, delay in payments by government institutes, and disputes between PEPCO, AJK and FATA on immediate basis. Thermal capacities of the existing power plants can be increased by using combined cycle plants. By employing combined cycle procedure at the power plants at Jamshoro, Guddu and Muzaffargarh at least an additional 1200 MW generation is possible as mentioned in Table 8. By using heat recovery steam generators, around 100 MW additional capacity can easily be added against every 200 MW of existing capacity.

8.2. Medium term plan

Large dams take roughly 10–15 years (depending on their size) for completion and engage a huge capital. The 4500 MW Diamer Basha dam was scheduled to be completed in 2022. Over investment in large dams can engage a huge capital and cause inflation in the country. Future identification and allocation of resources when there will be energy scarcity must be taken into consideration to secure future of the country. Share of solar and wind power in the global energy mix is growing rapidly and per unit cost may become competitive with conventional generation in near future. In Pakistan about 40,000 villages are still without electricity, most of them far away from the national grid. The cheapest solution to provide electricity to these villages is through solar and wind. Moreover solar and geo thermal can be used to fulfill the heating requirements and thus conserve fuel. Nuclear power is also the cheapest solution after hydro and a suitable option for medium term requirements.

8.3. Long term plan

Geo-thermal, ocean related resources, hydrogen based fuel cells etc. may be considered for long term planning and energy mix diversification. Most of these resources are not fully mature and pilot power plants have been installed worldwide to estimate their benefits at bulk level.

9. Conclusions

Pakistan's electricity requirements will triple by 2050. If sufficient resources are not allocated, the energy crisis in the country will intensify. An independent energy authority at the national level is required to make future plans for the development and utilization of indigenous resources like hydro, coal, nuclear and renewables. It is also required to analyze the available options to import energy from neighboring countries in order to secure the future of the country. The comparison of TAPI and IPI with LNG import options reveals the suitability of LNG over the gas pipelines. The optimum utilization of existing installed thermal generation and use of combined cycle power plants is imperative. Pakistan has abundant potential of renewable energy resources. The issue of circular debt can be minimized by introducing more renewable energy in the national grid.

References

[1] International Energy Agency France (IEA). Key world energy statistics, ⟨http://www.iea.org/publications/freepublications/publication/kwes.pdf⟩; 2012 [accessed May 2013].

[2] Alternate Energy Development Board. MoWP GoP Pakistan, ⟨http://www.aedb.org/parl.htm⟩; 2013 [accessed May 2013].

[3] Ghaffar MA. The energy supply situation in the rural sector of Pakistan and the potential of renewable energy technologies. Renew Energy 1995;8:941–76. http://dx.doi.org/10.1016/0960-1481(94)00034-0.

[4] Amer M, Daim TU. Application of technology roadmaps for renewable energy sector. Technol Forecast Soc Change 2010;8:1355–70. http://dx.doi.org/10.1016/j.techfore.2010.05.002.

[5] Asif M. Sustainable energy options for Pakistan. Renew Sustain Energy Rev 2009;4:903–9. http://dx.doi.org/10.1016/j.rser.2008.04.001.

[6] Amjid SS, Bilal MQ, Nazir MS, Hussain A. Biogas, renewable energy resource for Pakistan. Renew Sustain Energy Rev 2011;6:2833–7. http://dx.doi.org/10.1016/j.rser.2011.02.041.

[7] Bhutto A, Bazmi A, Zahedi G. Greener energy: issues and challenges for Pakistan—Biomass energy prospective. Renew Sustain Energy Rev 2011;6:3207–19. http://dx.doi.org/10.1016/j.rser.2012.12.010.

[8] Sahir MH, Qureshi AH. Specific concerns of Pakistan in the context of energy security issues and geopolitics of the region. Energy Policy 2007;4:2031–7. http://dx.doi.org/10.1016/j.enpol.2006.08.010.

[9] Chien T, Hu JL. Renewable energy: an efficient mechanism to improve GDP. Energy Policy 2008;8:3045–52. http://dx.doi.org/10.1016/j.enpol.2008.04.012.

[10] Amer M, Daim TU. Selection of renewable energy technologies for a developing county: a case of Pakistan. Energy Sustain Dev 2011;4:420–35. http://dx.doi.org/10.1016/j.esd.2011.09.001.

[11] Muneer T, Asif M. Prospects for secure and sustainable electricity supply for Pakistan. Renew Sustain Energy Rev 2007;4:654–71http://dx.doi.org/10.1016/j.rser.2005.05.001.

[12] Sahir MH, Qureshi AH. Assessment of new and renewable energy resources potential and identification of barriers to their significant utilization in Pakistan. Renew Sustain Energy Rev 2008;1:290–8. http://dx.doi.org/10.1016/j.rser.2006.07.002.

[13] Mirza UK, Ahmad N, Majeed T. An overview of biomass energy utilization in Pakistan. Renew Sustain Energy Rev 2008;7:1988–96. http://dx.doi.org/10.1016/j.rser.2007.04.001.
[14] Alam ZN, Alam NZ, Hisamuddin N. Review of geothermal energy resources in Pakistan. Renew Sustain Energy Rev 2009;1:223–32. http://dx.doi.org/10.1016/j.rser.2007.07.010.
[15] Mirza UK, Ahmad N, Harijan K, Majeed T. A vision for hydrogen economy in Pakistan. Renew Sustain Energy Rev 2009;5:1111–5. http://dx.doi.org/10.1016/j.rser.2008.08.005.
[16] Ashraf CM, Raza R, Hayat SA. Renewable energy technologies in Pakistan: prospects and challenges. Renew Sustain Energy Rev 2009;6:1657–62. http://dx.doi.org/10.1016/j.rser.2008.09.025.
[17] Shifa FA, MFU. Butt. A feasibility study for deployment of wind energy based power production solution in Islamabad, Pakistan. IEEE Proc Emerg Technol (ICET) 2012:1–6. http://dx.doi: 10.1109/ICET.2012.6375500.
[18] Farooq MK, Kumar S. An assessment of renewable energy potential for electricity generation in Pakistan. Renew Sustain Energy Rev 2013;20:240–54. http://dx.doi.org/10.1016/j.rser.2012.09.042.
[19] Depuru SSSR Lingfeng W, Devabhaktuni V. Smart meters for power grid: challenges, issues, advantages and status. Renew Sustain Energy Rev 2011;6:2736–42.
[20] Javaid N., Sharif A., Mahmood A., Ahmed S., Qasim U., Khan Z.A. Monitoring and Controlling Power Using Zigbee Communications. In: IEEE proceedings on seventh international conference on broadband, wireless computing, communication and applications (BWCCA); 2012. p. 608-13.
[21] Baig F, Mahmood A, Javaid N, Razzaq S, Khan N, Saleem Z. Smart home energy management system for monitoring and scheduling of home appliances using Zigbee. J Basic Appl Sci Res 2013;3:880–91.
[22] Khan I, Mahmood A, Javaid N, Razzaq S, Khan RD, Ilahi M. Home energy management systems in future smart grids. J Basic Appl Sci Res 2013;3:1224–31.
[23] Ullah MN, Mahmood A, Razzaq S, Ilahi M, Khan RD, Javaid NA. Survey of different residential energy consumption controlling techniques for autonomous DSM in future smart grid communications. J Basic Appl Sci Res 2013;3:1207–14.
[24] Shah AA, Qureshi SM, Bhutto A, Shah A. Sustainable development through renewable energy—the fundamental policy dilemmas of Pakistan. Renew Sustain Energy Rev 2011;1:861–5. http://dx.doi.org/10.1016/j.rser.2010.09.014.
[25] Sheikh MA. Energy and renewable energy scenario of Pakistan. Renew Sustain Energy Rev 2010;1:354–63. http://dx.doi.org/10.1016/j.rser.2009.07.037.
[26] Sheikh MA. Renewable energy resource potential in Pakistan. Renew Sustain Energy Rev 2009;9:2696–702.
[27] Population Clock at Population Census Organization. GoP, ⟨http://www.census.gov.pk/index.php⟩; [accessed Nov 2012].
[28] Hydrocarbon Development Institute of Pakistan (HDIP). Energy yearbook 2010, 2011.
[29] Malik A. Power Crisis in Pakistan: A Crisis in Governance? Pakistan Institute of Development Economics 2012; No. 2012: 4.
[30] Ministry of Finance, GoP. ⟨http://www.finance.gov.pk/survey/chapter_12/ExecutiveSummary.pdf⟩; [accessed May 2013].
[31] Khan N. Water conflicts and hydroelectricity in South Asia. Global Res 2012;2012:1–12.
[32] National Transmission and Despatch Company Ltd. (NTDC) Pakistan. Electricity demand forecast based on multiple regression analysis, Feb 2011.
[33] National Transmission and Despatch Company Ltd. (NTDC) Pakistan. Electricity marketing data 30th June 2011. 36th Issue.
[34] Water Resource Development Council Pakistan. ⟨www.wrdc.com.pk⟩; [accessed May 2013].
[35] Private Power and Infrastructure Board Pakistan. Hydro power resources of Pakistan. ⟨http://www.ppib.gov.pk/HYDRO.pdf⟩; [accessed May 2013].
[36] State Bank of Pakistan. Annual report 2010–2011, the state of Pakistan's economy.
[37] National Transmission and Despatch Company Ltd. (NTDC) Pakistan. Data reference book, 4th Issue 2011.
[38] Ali SS, Badar S. Dynamics of circular debt in Pakistan and its resolution. Lahore J Econ 2010;15:61–74.
[39] Cohen A, Curtis L, Graham O. The proposed Iran–Pakistan–India gas pipeline: an unacceptable risk to regional security. Herit Found Wash DC 2008:30.
[40] Anas M, Javaid N, Mahmood A, Raza SM, Qasim U, Khan ZA. Minimizing Electricity Theft Using AMI. In: IEEE proceedings on seventh international conference on P2P, parallel, grid, cloud and internet computing. Victoria, Canada; 2012: p. 176–82.
[41] Choudhary MA, Khan N, Ali A, Abbas A. Achievability of Pakistan's 2030 Electricity Generation Goals Established under Medium Term Development Framework (MTDF): Validation Using Time Series Models and Error Decomposition Technique. In: IEEE proceedings on energy 2030 conference; 2008: p. 1–10.
[42] REN21 Secretariat Paris. Renewables 2012 global status report. (⟨http://www.ren21.net/Portals/0/documents/Resources/%20GSR_2012%20highres.pdf⟩; [accessed May 2013].
[43] Energy Expert Group. Economic advisory council, ministry of finance Pakistan. Integrated energy plan 2009–2022.
[44] ⟨http://www.riazhaq.com/2009/04/pakistan-pursues-several new.html⟩; [accessed May 2013].
[45] ⟨http://solar-energy-system.blogspot.com/2007/12/solar-radiation-map-of-world.html⟩; [accessed May 2013].
[46] Global Wind Energy Council. Global wind report annual market update 2011.
[47] National Renewable Energy Laboratory (NREL) USA ⟨http://www.nrel.gov/international/pdfs/pak wind.pdf⟩; [accessed Nov 2012].
[48] Zaigham NA, Nayyar ZA. Renewable hot dry rock geothermal energy source and its potential in Pakistan. Renew Sustain Energy Rev 2010;3:1124–9.
[49] Bhutto AW, Karim S. Coal gasification for sustainable development of the energy sector in Pakistan. Energy Sustain Dev 2005;4:60–7.
[50] Chaudhry MM. Role of water resources development in the economy of Pakistan ⟨http://pecongress.org.pk/images/upload/books/Paper658.pdf⟩; [accessed May 2013].